USING ISAAC TO EXPLORE THE IMPACT OF RECONNAISSANCE ON MISSION SUCCESS

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Introduction

Military Systems Experimentation Branch and Land Operations Division of the Australian DSTO have been examining the utility of agent-based distillations (ABD's), and the method of Operational Synthesis, in assisting traditional operational analysis techniques to investigate future warfighting concepts. This paper will focus on an operational synthesis case study of reconnaissance and surveillance (R&S), used to support the Army Experimental Framework (AEF), to highlight issues for the application of the technique. The source of the case study was a wargame at the Headline Experiment 2000 (HE00), the major experimental activity for AEF in 2000.

The Army Experimental Framework (AEF) supports the Army's continuous modernisation program by providing an analytical framework to define, test and refine capabilities and concepts [1]. The AEF 2000 (AEF00) examined future force structure options and concepts for a mechanised task force within the Manoeuvre Operations in the Littoral Environment (MOLE) concept. The HE00 was the major analytical event within AEF00. The aim for the HE00 was to assess the war-fighting concept and structure for an Enhanced Combat Force (ECF) heavy/medium Task Force (TF) for the Defence of Regional Interests (DRI) out to 2016, in order to inform force development [2]. The method used was a two level Command Post Exercise (CPX) driven by the Janus Wargame. Data on the performance of the forces being examined was collected using a variety of automated and observational techniques.

The wargame demonstrated the critical reliance that light and highly mobile forces have on R&S. The dependence was most apparent when conducting manoeuvre operations at high tempo while attempting to mass effects on an enemy and remaining at "arms length" from his strengths. The effectiveness of R&S was also found to degrade as terrain complexity increased [3].

This paper details the ABD modelling of a reconnaissance scenario that was conducted during the 4th Project Albert Workshop, which was held in Cairns, Australia from 6 – 10 Aug 01. It was hoped that the results generated would demonstrate how these tools can assist the analysis of future warfighting concepts from a number of perspectives as well as highlight issues for the successful application of the technique.

Operational Synthesis

Operational synthesis is an analysis method initiated by the US Marine Corps Combat Development Command to explore new and novel war fighting concepts by the application and integration of existing tools and techniques [4]. However, the application of a number of analysis techniques to robustly investigate emerging war fighting concepts is not new, and in fact it has long been a principle of military operations analysis techniques [5]. Operational synthesis is novel, however, in that it attempts to integrate across a range of simulation tools and operational analysis techniques that includes ABD's.

ABDs are simple, easy to use, transparent simulations that abstract away from the traditional detailed physics modelling of battlespace entities and instead focus on the personalities and non-physical interactions of the entities within the simulation. In general the current suite of military simulations do not adequately represent these non-physical human aspects [6]. ABDs can begin to satisfy this requirement, but at the expense of detailed physical modelling.

The uncomplicated nature of ABDs makes them useful for the rapid investigation of a large problem space through a process known as data farming [7] to identify significant trends and high payoff areas for more focussed analysis. Data farming also allows extensive parameter excursions to be performed, both in terms of variations in platform capabilities and tactics (behavioural characteristics), from the baseline scenario. This then enables multi-variable sensitivity analyses to be performed to explore any non-linear behaviour and synergies in the system. The farmed data can also be used to perform statistical analyses to test the significance of the properties observed.

However, their limitation is that they are not at a sufficient level of fidelity to inform capability development decisions with any degree of confidence. Hence the linking of ABDs to higher fidelity analysis techniques at multiple stages in an analysis methodology should provide a greater degree of analytical rigour than ABDs alone.

Reconnaissance Scenario

Observations made during HE00 showed that success for the Blue force relied heavily on reconnaissance at the tactical level for collecting and maintaining situation awareness (SA). It was stated that “the military judgement collected in the seminars confirmed that the Light Armoured Vehicle (LAV) basis for the force places a heavy reliance on SA in order to manoeuvre around enemy strengths or to mass effects to defeat the enemy in given locations” [2]. It was also noted “…The experiment confirmed that manoeuvre strengths in open terrain would be nullified by the characteristics of complex terrain. The force no longer had the ability to remain beyond ‘arms length’ of the enemy”. These observations indicated that the R&S issue was fundamental to the performance of a force conducting manoeuvre operations.

Thus the analytical focus of the study was to look at the balance of capabilities required to achieve the R&S functions and how these capabilities enable a force to fulfil its mission across a range of environments. The investigation was used as a vehicle for exploring the issues surrounding operational synthesis with the analytical outcomes being considered indicative rather than definitive of the actual concepts.

A working hypothesis relating battlefield survivability and the effectiveness of R&S was proposed. Figure 1 displays an influence diagram that describes the postulated relationship and which was used to focus the development of the scenario. This higher-level hypothesis can be broken into a number of more specific lower-level questions. The lower-level questions we attempted to study were:

Q1: ‘Does increased SA provide improved survivability?’

Q2: ‘What Blue force mix best provides this?’

Q3: ‘What capabilities and/or tactics are most critical?’

Q4: ‘How does terrain complexity affect Q1 – 3?’

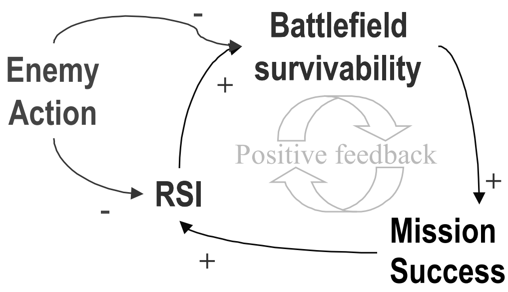

Figure 1 System Concept Under Study

Figure 2 illustrates the baseline scenario elements. The ABD modelling was conducted using the ISAAC model [8] in conjunction with the Maui High Performance Computing Center for the data farming. The battlefield consists of a two-dimensional play box of size 150 by 150. The physical and temporal dimensions were a 0.5km grid square and time steps of 1-minute intervals. For the baseline scenario the Blue force consists of 10 high lethality, low protection strike agents and 5 reconnaissance agents, while the Red force consists of 25 high lethality, high protection Red agents.

Table 1 shows the excursions from the baseline scenario that was used to investigate the lower-level questions. The two parameters varied were force mix (ORBAT) and terrain complexity. Force mix involved increasing the availability of indirect fire in excursion A, providing more reconnaissance assets in excursion B and finally trading reconnaissance assets for strike assets in Excursion C. Terrain complexity was varied from open to light complexity in alternative 1.

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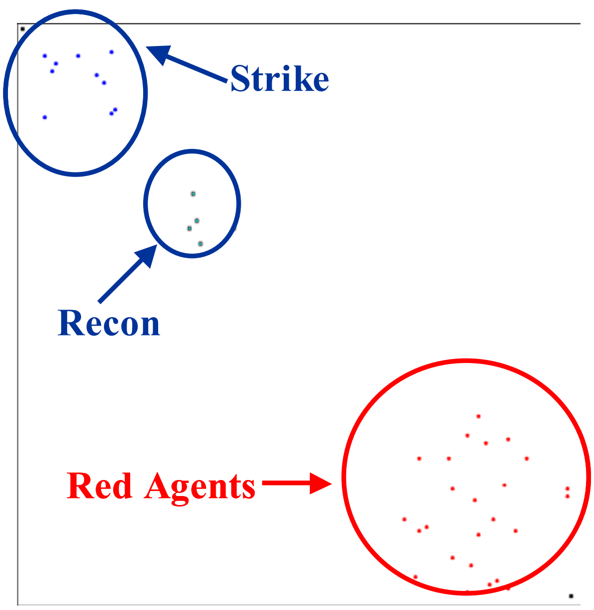

Figure 2 Baseline Scenario Elements

	Terrain Complexity	
ORBAT	**Baseline**	**Alt1**
Baseline	Open	Light
A. Indirect Fire	Open	Light
B. More Recon	Open	Light
C. Traded Recon	Open	Light

Table 1 Excursions from the Baseline

The strike agent had a superior sensor range compared to the Red agents but have relatively poorer weapon characteristics. The reconnaissance agents were equipped with 'spotlight' type sensors, faster mobility (thus approximating some form of UAV capability), assumed to be not targeted by Red, and were positioned forward of the strike agents. Their task was to survey the positions of the Red agents and communicate detections back to the strike agents. The strike agents moved towards the Red agents based on the information provided by the reconnaissance agents, and thus relied on good communications. Tactically, they would engage the Red agents once a numerical advantage was achieved.

Red was effectively static, defending its centre of gravity until Blue units were detected at which time they actively pursue them with an intent to engage. Whilst Red did not require a numerical advantage to attack Blue, they did require at least as many Red units nearby as there are Blue units. Physical attributes were coded in ISAAC using the parameter values given in the left hand side of Table 2 below. The tactical behaviours were modelled in ISAAC as a simple system of attraction-repulsion weightings, and were coded in ISAAC by using the parameter values given in the right hand side of Table 2.

	Strike	**Recon**	**Red**
Mobility	1	2	1
Sensor	10	4	6
Weapon Range	4	N/A	4
P(Kill)	0.4	N/A	0.5
Defence	2	999	2
Comms Range	80	80	0
Friendly	10	0	0
Enemy	20	50	50
Flag	1	1	0
Combat	5	N/A	0

Table 2 Baseline Model Parameters -- ISAAC Attributes and Personalities

Workshop Results

The Project Albert workshop format was as follows. The mornings of Day 1 and Day 2 consisted of briefings from each of the syndicate leaders about their respective problem and general presentations about Project Albert research efforts in various nations. The afternoons of Days 1 and 2 were devoted to syndicate discussions, while the evenings allowed opportunities to submit data farming requests to the Maui High Performance Computing Center (MHPCC). The morning of Day 3 was used to analyse the results and prepare a back brief that was given by each syndicate leader in the afternoon of Day 3. During the workshop the baseline and excursions B and C (Table 1) were investigated. The workshop analysis was restricted to the baseline terrain complexity due to limited time. The remainder of the excursions in Table 1 were investigated in a period following the workshop by DSTO analysts.

The first run was submitted to the MHPCC after 4 hours of scenario planning and discussion at the end of Day 1. Each parameter combination was simulated only 48 times. This value was chosen to ensure that indicative results would be available for analysis on Day 2. For this first excursion (Excursion C, Table 1), we were interested in examining the force mix of Blue and the strike characteristics. Three Blue parameters were subsequently varied:

1. The number of reconnaissance assets was traded one for one with strike assets
2. Combat threshold (minimum local advantage to attack)
3. Weapon range (under match to overmatch)

Figure 3 shows the variation of the percentage number of average Red and Blue losses as the number of reconnaissance assets and combat threshold were varied, but holding the Blue weapon range fixed at the baseline value. Both graphs indicate that there seems to be no real trend associated with different values of the combat threshold. This result at first seemed counter-intuitive, but it may well indicate that the combat rule was not often activated because there was minimal dispersion of the Blue agents.

The first graph indicates that there may be a slight optimum, in terms of Red losses, when five reconnaissance assets are present. The second graph is intuitive in telling us that as we trade more vulnerable strike assets for invincible reconnaissance assets we decrease the average number of Blue losses. These results serve to illustrate the ever-present balance between the need for information and a minimum fighting weight.

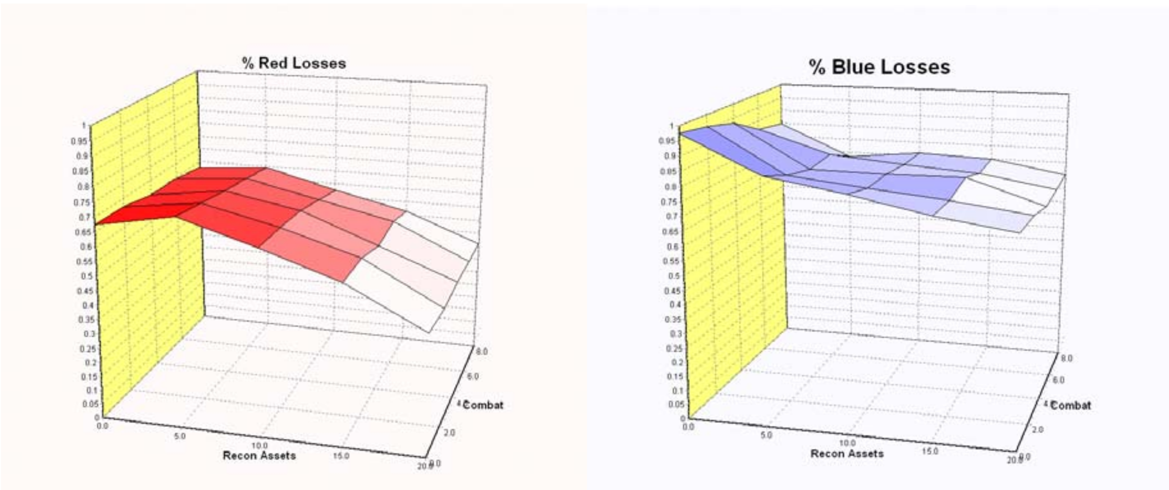

Figure 3 Number of Recon Assets vs. Combat Threshold

Figure 4 shows the variation of the percentage number of average Red and Blue losses as the number of reconnaissance assets and weapon range were varied, but holding the Blue combat threshold fixed at the baseline value. Firstly, we note that as soon as Blue has a weapon range overmatch against Red (i.e. > 4) it dramatically increases the average number of Red losses and decreases the average number of Blue losses. Similarly as soon as Blue has a weapon range under match (< 4) Red becomes far superior. Hence, relative weapon range appears to be a critical parameter in this scenario. The effect of trading strike assets for reconnaissance assets is minimal except perhaps when there is weapon range equality where it again appears that a local optimum may exist (as suggested in Figure 3).

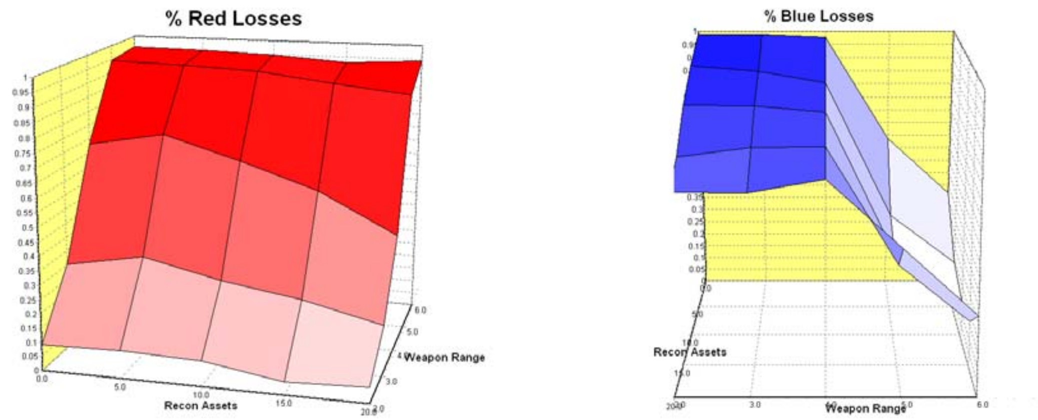

Figure 4 Number of Recon Assets vs. Weapon Range

The second run was submitted to the MHPCC at the end of Day 2 after more scenario planning and discussion and in view of the results from the first run. Each parameter combination was simulated 64 times after information about the total processing time was deduced from the first run. For this second excursion, interest turned to examining force augmentation to Blue and the reconnaissance characteristics (Excursion B, Table 1). Three Blue parameters were subsequently varied:

1. The number of reconnaissance assets[1]
2. Communications weight (the 'quality' of the information received)
3. Reconnaissance lethality

Initially, the intent was to modify the lethality of just the reconnaissance assets in order to simulate indirect fire. However the data farming tools currently don't allow squad specific changes so unfortunately the lethality of the strike assets was also changed. As a result, this didn't allow us to effectively study the effect of indirect fire during this excursion (Excursion A, Table 1). However, during our follow up data farming we have made an attempt to do this by submitting separate runs – see later.

The reduced set of results for this excursion is given in Figure 5, which shows the variation of the percentage number of average Red, and Blue losses as the number of reconnaissance assets and information quality were varied, but holding the reconnaissance lethality fixed at the baseline value. It should be pointed out that due to model constraints the reconnaissance assets axis is numbered in reverse order so at point 0 there are actually five reconnaissance assets and no reconnaissance assets at point 5. Somewhat surprisingly, the results seem to

[1] Note: in this scenario the number of reconnaissance assets was increased and the number of strike assets fixed, i.e. there is no trade off.

indicate that the effect of increasing the number of reconnaissance assets is minimal, though this rate of return is stronger with increased information quality.

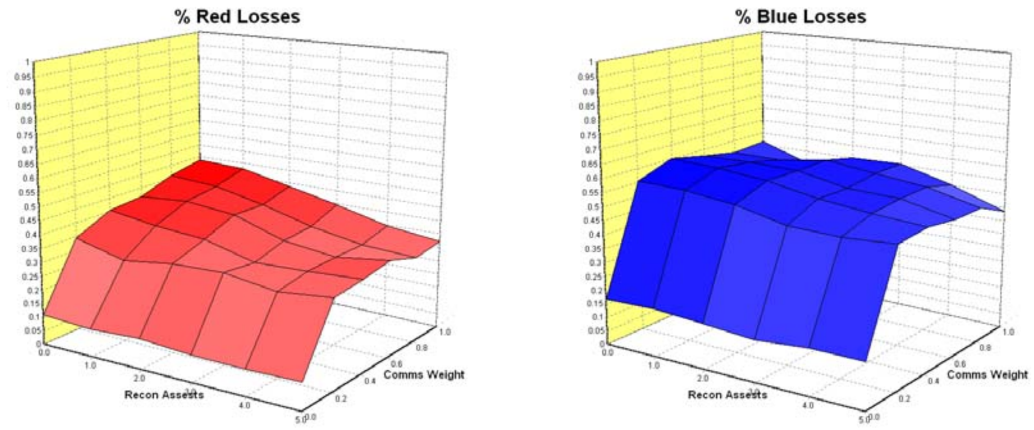

Figure 5 Number of Recon Assets vs. Communications Weight (0-1)

Interestingly, the first graph clearly seems to indicate that there is a significant advantage in increasing the amount of information from none to 'little'. However the second graph indicates that the Blue losses correspondingly increase. The fact that there are very few total losses when Blue has no communications seems to indicate there are very few engagements. As for the reason for a faster rate of increase in Blue losses than Red, the most logical reason is the dispersion of Blue. With low communications weight there is more dispersion as each entity is acting mainly on their own local information. As communications weight increases the units are gradually drawn to each other, as they all tend to go to areas of high Red concentration making them more grouped and an easier target. Red has no communications and does not suffer from the grouping problem as they act independently. Finally, it would also be interesting to determine whether the 'jump' between 0 and 0.2 on the communications weight axis is gradual or in fact very steep.

Additional Data Farming

In the weeks following the workshop several additional runs were submitted to the MHPCC to further analyse the scenario. The first was alluded to in the previous section and involved honing in on the 'interesting' portion of the graphs from Figure 5. The same two parameters were varied in Figure 6 below except that the communications range was only varied between 0 and 0.4 but in smaller increments, and the number of runs for each parameter combination was increased to 96 to produce more reliable statistics.

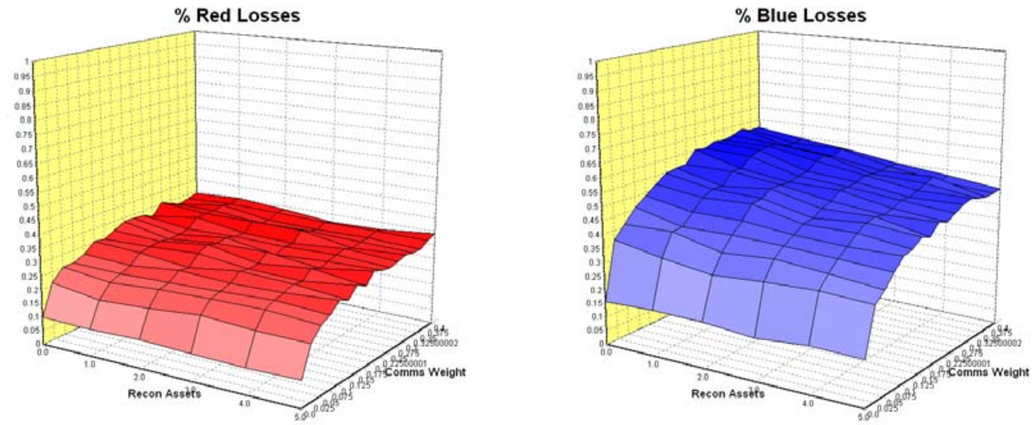

Figure 6 Number of Recon Assets vs. Communications Weight (0-0.4)

The results show that the increase appears to exhibit decreasing returns and thus suggests that there may be little point in improving the quality of information beyond some threshold level (if Red losses is the measure of effectiveness). This type of analysis may provide insights into answering questions like 'How much do I need to know about the enemy before I commit my troops'. Alternatively the communications weight parameter could be viewed as a surrogate for the level of trust placed in an entities commander.

In order to examine the robustness of some of the previous results across different terrain types a surrogate for terrain was introduced. In order to simulate a shift from open terrain to light terrain (Alt 1, Table 1) the sensor ranges of all entities were decreased so that the total area sensed was approximately halved in each case. Table 3 details the changes for the respective terrain types.

Open/Light	**Strike**	**Recon**	**Red**
Speed	1 / 1	2 / 2	1 / 1
Sensor	**10 / 7**	**4 / 3**	**6 / 4**
Fire	4 / 4	2 / 2	4 / 4
Lethality	0.25 / 0.25	0 / 0	0.5 / 0/5

Table 3 Parameter Modifications for Terrain Type

Runs were submitted to the MHPCC varying the number of reconnaissance assets from 1 to 10 and simulating the scenario 1024 times for each variation. This illustrates the advantage of models like ISAAC and access to supercomputing facilities in that significantly increased samples sizes can be generated. Figure 7 suggests that in light terrain there may be some form of compromise required when deciding whether to trade strike for reconnaissance (Excursion C, Table 1). As the number of strike agents traded increases, the number of Red losses decreases (which is undesirable) however the number of Blue losses also decreases (which is desirable). This raises the question as to which MOE is more important. If both are equally important then the loss exchange ratio (LER) could be used to examine whether an optimum exists. The results for the open terrain case show very few losses for both sides. This may suggest that the increased level of awareness on both sides resulted in very few engagements.

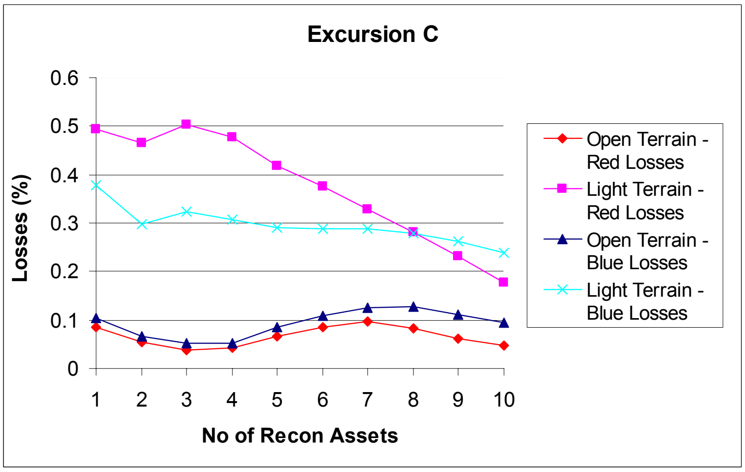

Figure 7 Effect of Trading Strike for Recon Assets in Different Terrain Types

Figure 8 suggests that the number of Red losses appears independent of the number of reconnaissance assets augmented (Excursion B, Table 1) to the Blue force in both open and light terrains. However, the number of Red losses almost doubles in light terrain. This may occur because Red does not possess a stand off capability in light terrain, as modelled here. Red has a sensor range of four and is unable to retreat from Blue before they are fired upon as both sides have a weapon range of four. Blue is unaffected by this stand off problem as their sensor range in light terrain is seven, giving them a sensor overmatch due to their postulated superior technology.

The curves showing average Blue losses indicate a somewhat counter-intuitive result, in that adding reconnaissance agents increases the number of Blue losses. This result is repeated in both open and light terrain. However, given the earlier result of there being more Red losses in light terrain, it is reasonable to expect that there would then be less Blue losses in light terrain, as the graph indicates.

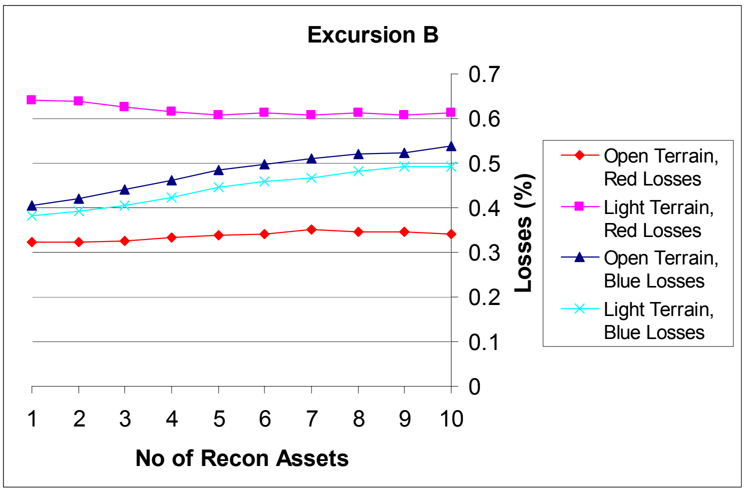

Figure 8 Effect of Adding Strike Assets in Different Terrain Types

As mentioned earlier, in order to simulate indirect fire (Excursion A, Table 1) the reconnaissance agents were given lethality capability and added to a fixed number of strike agents, see Figure 9 below. When the number of reconnaissance agents was varied from 1 to 10 in light terrain the average number of Red losses increased linearly while the average number of Blue losses decreased linearly, as would be expected with the increased firepower.

However it is interesting to note that in the open terrain scenario the number of Red losses only increases when there is between one and five reconnaissance agents, while after this the number of Red losses remains constant. Meanwhile, Blue losses appear constant regardless of how much indirect fire and reconnaissance assets are present. The combination of all of these results tend to suggest that there is a limit as to how much indirect fire is useful in open terrain, while in light terrain this limit may still be present but the threshold may be much higher.

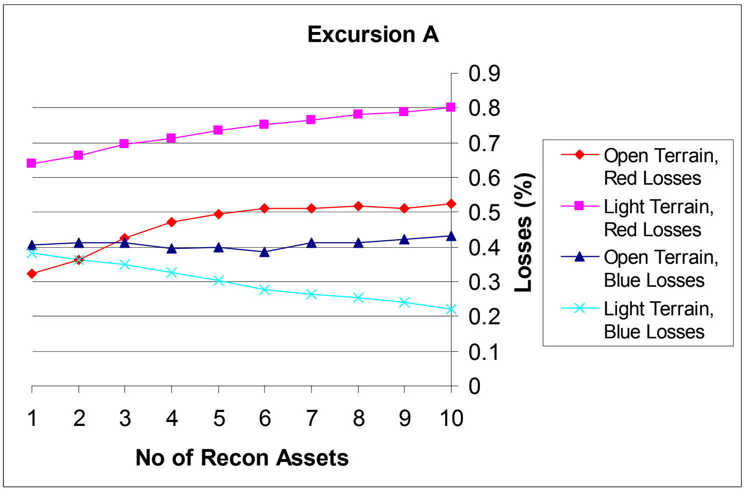

Figure 9 Effect of Adding More Indirect Fire

When reconnaissance and strike assets were traded, the average number of Red losses was very high and virtually constant regardless of how many strike assets were traded for reconnaissance assets. This could be explained by thinking of the trade of reconnaissance assets (with lethality to simulate indirect fires) and strike assets as a trade of firepower for similar firepower. The limitation of the modelling was such that the associated time delay to call in indirect fires (and the resultant decreased in effectiveness) was not modelled. However the number of Blue losses quickly reduced to almost zero as the number of reconnaissance assets increases. This again is intuitive because we are trading relatively unprotected strike assets for highly stealthy, and hence survivable, reconnaissance assets.

Other Modelling

A principle of operational synthesis is the application of a number of analytical techniques to a single problem. CASTFOREM is a closed loop, event driven, stochastic simulation of the combined arms battle, and was able to model the same scenario and excursions as ISAAC in Table 1 with a higher degree of fidelity but with a reduced scope in terms of the farmed parameters. A CASTFOREM study performed before the workshop was thus used to complement the analysis performed by ISAAC. Here, only a summary of the results will be given and the reader is referred to [3] for further information.

The CASTFOREM results showed that in the baseline scenario Blue has a slight advantage over Red. In Excursion A both the Red and Blue losses increase slightly over the baseline with additional indirect fire assets. However when the number of reconnaissance assets is doubled in Excursion B, Blue inflicts more losses on Red while their Blue losses remain the same as the baseline. Overall they still only have a slight victory. Comparing Excursions A and B suggests that, in this scenario, an investment in reconnaissance and target acquisition has a higher payoff that an investment in indirect fires.

In Excursion C where the reconnaissance assets were traded off for strike assets, there was a similar result to the baseline in terms of losses to both sides and the overall number, resulting in a slight victory for Blue. In this case the model indicated that the force was not sensitive to trading off some strike assets for reconnaissance assets.

However in light vegetation (Alt 1, Table 1) where Red experience a decrease in losses and Blue an increase due to the increase in terrain complexity, Blue suffer a slight defeat in the baseline. In Excursion A and C Blue are able to achieve a slight advantage, hence additional indirect fires or higher levels of reconnaissance (traded for strike in Excursion C) go part way to negating the impact of increased terrain complexity. By far the most interesting result is the impact of additional reconnaissance in Excursion B that leads to a significant victory in light terrain. This result would suggest that additional reconnaissance in combination with the baseline strike assets is a decisive advantage in light terrain. Such a result, while significant in the context of the other results, is the subject of further investigation using higher fidelity terrain models in CASTFOREM.

Table 4 collates the results from the CASTFOREM and ABD models for the various Excursions listed in Table 1 (taken from [3]). When the results from ISAAC and CASTFOREM are correlated they suggest an investment in reconnaissance or additional strike assets can lead to Blue force being more successful as terrain complexity increases. However analysis from HE00 suggests that this trend would not continue into dense terrain (as opposed to open and light) if the same tactics were maintained. As a result the size of the terrain parameter excursion in the tools was not large enough to synthesis this potentially significant result [3].

Blue Success / Failure	**Terrain Complexity**			
ORBAT	**Baseline**		**Alt1**	
	CAST	**ABD**	**CAST**	**ABD**
Baseline	☑	☒	☒	☑☑
A. More Indirect Fire	☑	☑	☑	☑☑
B. More Recon	☑	☒	☑☑	☑☑
C. Traded Recon	☑	☒	☑	☑☑

Table 4 Comparison of Blue success across Excursions and Alternative as indicated by the Loss Exchange Ratio (LER) [2,3].

[2] LER is the ratio of Red Losses to Blue Losses.

[3] ☑ Slight Blue victory (1.0 < LER < 1.2)

Conclusions

The workshop clearly showed that the ISAAC model is a useful tool for generating a broad level of discussion amongst defence analysts and military personnel (a tool for thinking with). This enabled both the scenario and concept to be explored and refined in a short period of time. It was found that the visualisation of the two-parameter landscapes was useful to capture both the broad effects (direction and magnitude) of varying single parameters as well as identifying any trade offs and synergies between pairs of parameters.

However, two-parameter landscapes generally don't allow the deduction of causes for these effects. Rather, the interactive nature of the model does allow the suggestion of possibilities (mainly from professional military judgement), which can be useful starting points for other (possibly higher resolution) models in an operational synthesis approach.

The specific insights gained from the ISAAC results have provided trends to compare and contrast with against higher resolution models (e.g. the effectiveness of reach-back), as well as providing a set of precautions (e.g. reconnaissance tactics) to watch out for. Having said this, however, the model and supporting tools still have a number of limitations. In particular, it was found that the modelling of surveillance and intelligence was very difficult, as was generating variable interaction between force types. Finally, the data farming tools were incapable of ranging over squad specific parameters.

What currently makes ABDs attractive is that they can be applied across a wide range of problem domains, simply and quickly. The approach being pursued by Military Systems Experimentation Branch, DSTO is to continue to use ABDs as low fidelity tools in an operational synthesis framework to scope a wide problem domain to indicate high payoff analysis areas for higher fidelity tools. Our goal is to improve the strength of the links between ABDs and other tools through the use of system frameworks in which to situate and relate each model and the subsequent results [3].

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- MAJ Steve Fomiatti, Combined Arms Training Development Centre, Australia
- Dr Shujie Chang, MARFORPAC, USA

☑☑ Significant Blue victory (LER > 1.2)

☒ Slight Blue loss (0.8 < LER < 1.0)

☒☒ Significant Blue loss (LER < 0.8)

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